

GHRs Monitoring of the Outflowing Material in NGC 4151

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Abstract. We present the results of a GHRs program to monitor the absorption lines in the spectrum of the Seyfert 1 galaxy NGC 4151 caused by outflowing gas from the nucleus. Although we see subtle changes over the four year period in the GHRs spectra of the broader of the absorption features, the wavelength constancy of all the features is remarkable. The limits on the secular acceleration suggest that either (1) The absorbing clouds are well beyond the broad emission line region, or (2) The clouds are experiencing significant drag from an intercloud medium. The exception to this constancy occurred during one of the epochs of our monitoring when a broad shallow C IV trough appeared at an outflow velocity of 3750 km s^{-1} and then subsequently disappeared.

1. Observations

NGC 4151 is one of the nearest, brightest and most studied of the classical Seyfert galaxies and is considered the prototype Type 1 Seyfert. In addition to its broad permitted lines, it has been recognized for many years that there were also blueward-displaced absorption features present, indicating the presence of outflowing gas. GHRs observations of the nucleus of NGC 4151 were made over five epochs spanning 1992 June 22–27 (Epoch 1), 1992 July 4 (Epoch 2), 1994 January 3 (Epoch 3), 1994 October 28–29 (Epoch 4), and 1996 March 11 (Epoch 5). The flux calibrated observations of the C IV absorption are shown in figure 1

2. Profile Fitting and Limits on Kinematic Variability

Normalized spectra were produced by dividing the flux data and their corresponding error vectors by a continuum + emission line fit. The absorption line strengths (refer to Figure 2 for line IDs) were measured using the ‘specfit’ task in IRAF (Kriss 1994), using combinations of *tauabs* models (Gaussian function

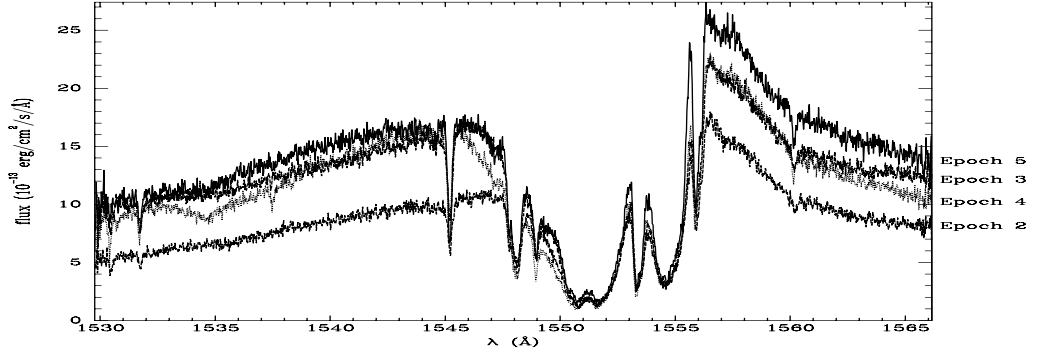


Figure 1. C IV absorption in the GHRS spectra of NGC 4151

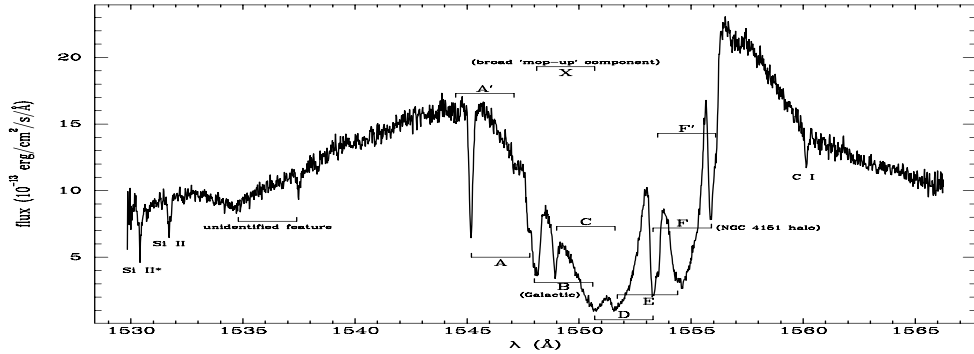


Figure 2. C IV component IDs

in optical depth) and *labsorp* (Gaussian in equivalent width). Figure 3 contains plots of $\log N$ vs v_{obs} and $\log N$ vs FWHM for both the C IV components and the Mg II components.

In Epoch 4, a wide trough was observed at $\sim 1534.5\text{\AA}$. It is almost certainly not the result of a defect on the photocathode. It remains a possibility that the apparent absorption is in fact a combination of an offset emission feature (related to the satellite features of Ulrich et al. 1985), and a poor fit to the resulting line and continuum. However, the wavelength of the Ulrich et al. 1985 L1 feature is 1523.5\AA , significantly bluer than is needed to easily explain this absorption.

3. Limits on secular acceleration of the absorbing clouds

Inspection of Figures 1 and 3 shows that over the time covered by the observations at Epochs 2–5, while there have been some small changes in the absorption profiles (notably the appearance of the high velocity transient at epoch 4), the gross properties have been remarkably stable. *In particular, we find no evidence for any secular change in velocity in the well defined A and C components.* A fairly conservative limit on any secular steady acceleration for these is about $1 \times 10^{-3} \text{ cm sec}^{-2}$.

We consider two naive interpretations of this limit on the acceleration:

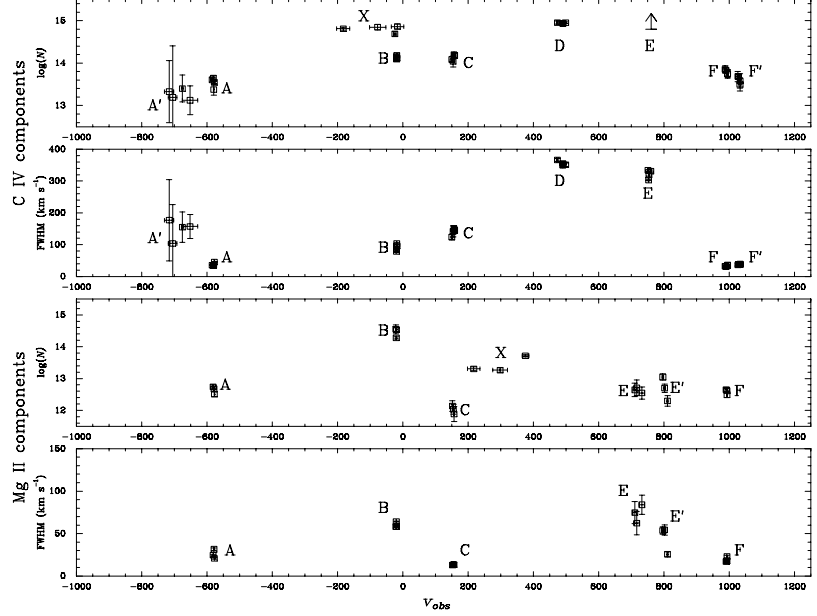


Figure 3. Column density and FWHM vs velocity for C IV and Mg II. The FWHM values for Component X do not appear on this scale.

(1) The clouds are undergoing free radiative acceleration. For an order of magnitude estimate, we can consider them to be optically thin to both lines and continua. With some reasonable assumptions about abundance and geometry, the limit on the secular free acceleration would require the cloud to be at a distance of about $1.7 \times 10^{18} \times D_{10}$ cm, where D_{10} is the distance from us to NGC 4151 in units of 10 Mpc. This is far beyond the broad emission line region, which, on the basis of reverberation studies (Clavel et al. 1990) is of order 10^{16} cm.

(2) In the second naive model, we assume that a cloud is exposed to radiative acceleration, as estimated above, with a distance from the central source comparable to the size of the broad emission line region (i.e., about 10 cm s^{-2}), but that drag against a hot confining medium counteracts the radiative acceleration. A static medium with a density as low as about 10^2 cm^{-3} would exert enough drag on the clouds to prevent detectable acceleration. However, a static medium seems very unlikely, since its drag would prevent the clouds from reaching their observed terminal velocities. A more likely scenario would involve an expanding and accelerating wind at higher density with a small velocity differential between the cloud and the accelerating wind (c.f. the discussion in Begelman, DeCool and Sikora 1991). There are two limiting situations: (a), where we assume that the acceleration commences at the scale associated with the C IV broad emission line region (BELR). Then the cloud must be well beyond the BELR, as we inferred for the ballistic radiatively accelerated scenario. Or (b), where we require that the absorbing cloud be at, or only very slightly beyond, the C IV BELR, as is generally assumed. Then the acceleration must commence at a distance very

much smaller than the BELR in order that we currently not be able to detect the acceleration.

Implicit in both these scenarios is the assumption that we are observing the same material over the duration of our observations, rather than a flow pattern whose dynamical properties have not changed over several years.

4. Summary

The observations discussed here have some interesting similarities with the much more luminous Quasars. While outflow from Seyfert nuclei does not appear to be uncommon, the outflow velocities are generally restricted to velocities of order 3500 km s^{-1} or less – i.e., about 1/10 the velocities in the luminous BALQSOs. If the dominant accelerating mechanism is radiative and optically thin material is accelerated from rest beginning at some radius r_o upon being exposed to luminosity L , then the terminal velocity should scale as $V_\infty \sim (L/r_o)^{1/2}$. It appears that the range of ionization parameters characterizing the broad emission line region of AGNs is rather similar over the very large range of optical luminosities spanned by AGN, so that $L/(n_e \times r_o^2)$ is roughly constant. Moreover, most models infer rather similar electron densities over this range, so that one expects $r_o \sim L^{1/2}$ which leads to the scaling law $V_\infty \sim L^{1/4}$. The difference in luminosities between the rather modest Seyfert luminosity of NGC 4151 and the most luminous BALQSOs is about 10 magnitudes, implying a range in terminal velocities of about 10, which is roughly what is observed. Almost no work has been done to explore the terminal velocities of BAL-type objects near what is generally considered to be the dividing line between QSOs and Seyferts (ie. about $M = -23$), if there are such objects, and it would be of interest to see if they fall along such a sequence.

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